

AGRICULTURE WATER USE EFFICIENCY IN THE UNITED STATES

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Water Use Efficiency

Efficient use of water by agriculture in the United States is a complex subject, often misunderstood both within and outside the scientific communities. Enhancements in agriculture water use efficiency (WUE) depend on productivity gains, depicted by consistent increases in outputs per unit inputs. This approach to WUE relies on its technical and economic definitions. As discussions move to irrigated agriculture, a hydraulic definition is also used. In addition irrigation efficiency definitions will be discussed later just prior to the summary. Each WUE definition is briefly defined here as:

Water Use (technical) Efficiency: The mass of agricultural produce per unit of water consumed.

Water Use (economic) Efficiency: The value of product(s) produced per unit of water volume consumed.

Water Use (hydraulic) Efficiency: The portion of water actually used by irrigated agriculture of the volume of water withdrawn.

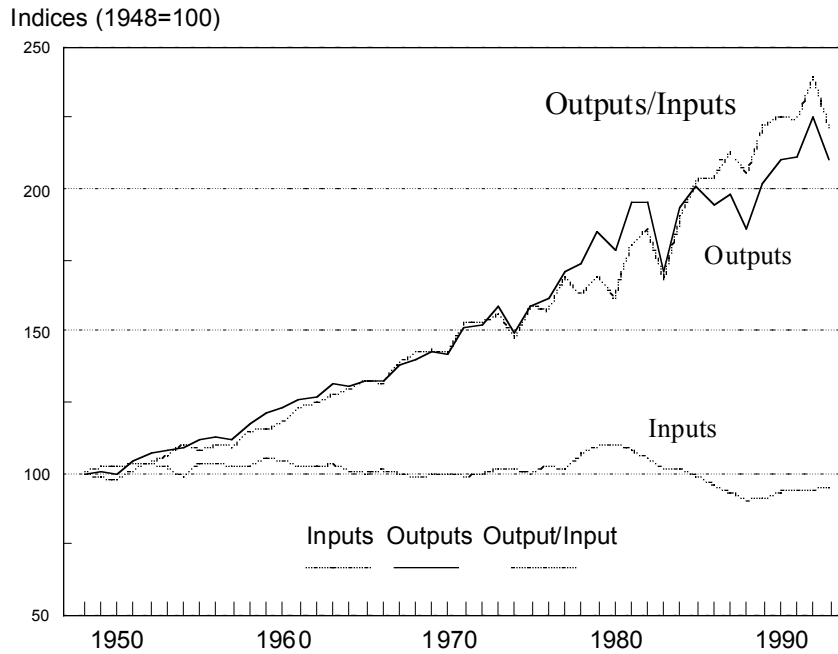
Productivity Gains

Increases in agriculture water use efficiency (WUE) in the United States are being depicted here by first summarizing productivity gains in the agriculture sector. These gains include both irrigated and non-irrigated (dryland) agriculture sectors. A more detailed discussion of water use efficiency as it pertains to irrigated agriculture will follow later.

Research and technology development have been the foundation for productivity gains in the agricultural sector, averaging 1.8 percent per year during 1948-93 (see Figure 1). The major gains in productivity over the last half of the century resulted from the introduction of chemicals (See Figures 2 and 3), and to a lesser degree plant and animal breeding programs as well as advances in water management.

Figure 1

Productivity Growth in U.S. Agriculture, 1948-1993



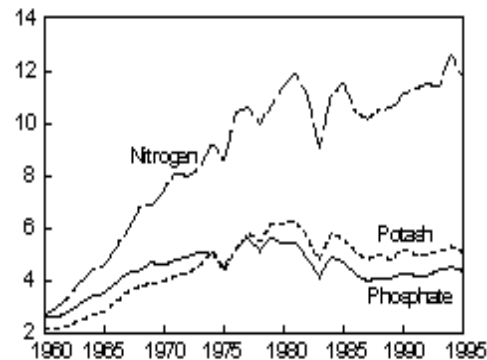
Source - USDA, Economic Research Service (ERS) estimates

Fertilizers and Pesticide Inputs

Increases in the use of commercial fertilizers and pesticides occurred mainly during the 1960's and 1970's. Commercial fertilizers provide low-cost nutrients to help realize the yield potential of new crop varieties and hybrids (Ibach and Williams, 1971). Since 1960, yields per unit of land area for major crops have increased dramatically. For example, average corn yield has increased from 55 bushels per acre in 1960 to 139 bushels in 1994 and average wheat yield from 26 to 38 bushels per acre. Pesticides, being the fastest growing agricultural production input in the post-World War II era (see Figure 3), have also contributed to the high productivity levels of U.S. agriculture.

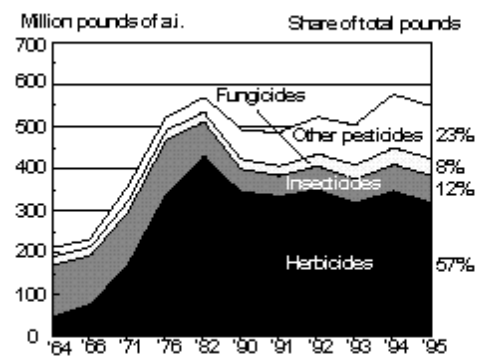
Figure 2 -- U.S. commercial fertilizer use, 1960-95

Million nutrient tons



Source: Compiled by ERS from Tennessee Valley Authority, 1994 and earlier issues; Association of American Plant Food Control Officials, 1995

Figure 3 -- Total pesticide use on major crops, 1964-95



Includes corn, cotton, soybeans, wheat, potatoes, other vegetables, citrus, and apples, and other fruit (about 67 percent of U.S. cropland).
Source: USDA, ERS estimates.

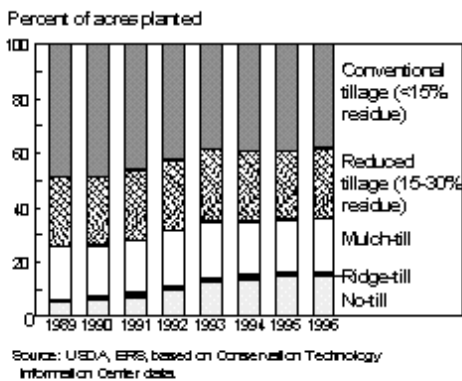
Crop Residue Management (CRM)

Crop residue management, which calls for fewer and/or less intensive tillage operations and preserves more crop residue from previous crops, is designed to protect soil and water resources and to provide additional environmental benefits. CRM is generally cost-effective in meeting conservation requirements and can lead to higher farm economic returns by reducing fuel, machinery, and labor costs while maintaining or increasing crop yields.

Conservation tillage, the major form of CRM, was used on almost 104 million acres in 1996, over 35 percent of U.S. planted cropland (see Figure 4).

Crop residues on the soil surface slow water runoff by acting as tiny dams, reduce surface crust formation, and enhance infiltration (Edwards, 1995). Combined with reduced water evaporation from the top few inches of soil and with improved soil characteristics, the higher level of soil moisture can contribute to higher crop yields in many cropping and climatic situations (CTIC, 1996). An example can be found west of the 100th meridian in the Great Plains, where the extra water stored by no-till will permit three- and four-year rotations to replace the two-year, wheat-fallow systems used for dryland production (English, C., White R., Chuang L., 1997). The changes in cultural practices and crop rotations increase the WUE by more effectively using the precipitation for crop production. This decreases the amount lost to soil evaporation, particularly during the fallow period. In some areas the every other year fallow results in excess water in the soil profile that moves with interflow and causes saline seeps which removes areas from crop production.

Figure 4 -- National use of crop residue management, 1989-96



Precision Farming Technologies

Through the use of global positioning systems (GPS) and associated geographic information systems, farmers are producing yield maps that allow them to discover problem sites within a field and vary application rates of seed, chemicals, and water. As an example, farmers who are using GPS and yield monitors on their combines are often noticing that yields jump when they cross subsurface drainage tile lines. This is encouraging them to install additional tile lines and has resulted in a dramatic increase in subsurface tile installation in the Midwest states.

Irrigation Water Management

The U.S. Department of Agriculture identifies improvements in water management as one of the primary agricultural policy objectives for the 1990's (USDA, 1994). Irrigation water management (IWM) involves the managed allocation of water and related inputs in irrigated crop production, such that economic returns are enhanced relative to available water. Conservation and allocation of limited water supplies is central to irrigation management decisions, whether at the field, farm, irrigation-district, or river-basin level.

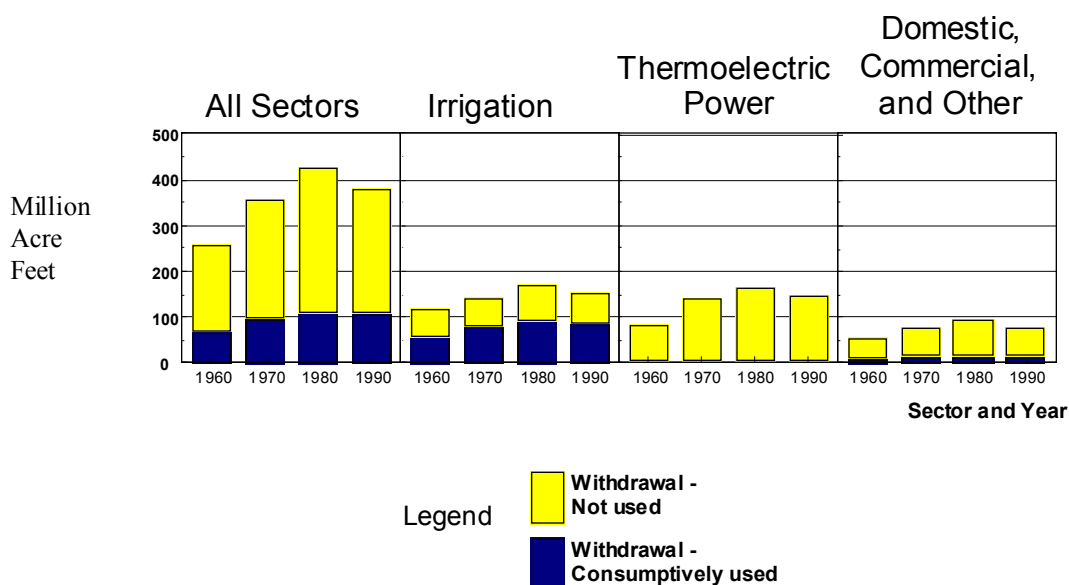
Why Manage Irrigation Water?

Irrigation water is managed to conserve water supplies, to reduce water-quality impacts, and to improve producer net returns.

Water Conservation. Water savings through improved management of irrigation supplies are considered essential to meeting future water needs. Irrigated agriculture is the most significant use of water, accounting for over 90 percent of freshwater withdrawals consumed in the Western States (includes Hawaii, Alaska and the seventeen contiguous western states) and roughly 80 percent nationwide (see AREI, Chapter 2.1 Water Use and Pricing). However, expanding water demands for municipal, industrial, recreational, and environmental purposes increasingly compete for available water supplies (see Figure 5). Since opportunities for large-scale water-supply development are limited, additional water demands must be met largely through conservation and reallocation of existing irrigation supplies (Moore,1991; Schaible and others, 1991; Vaux. 1986; Howe, 1985).

Figure 5.

U.S. Water Withdrawals and Use by Sector, 1960-90



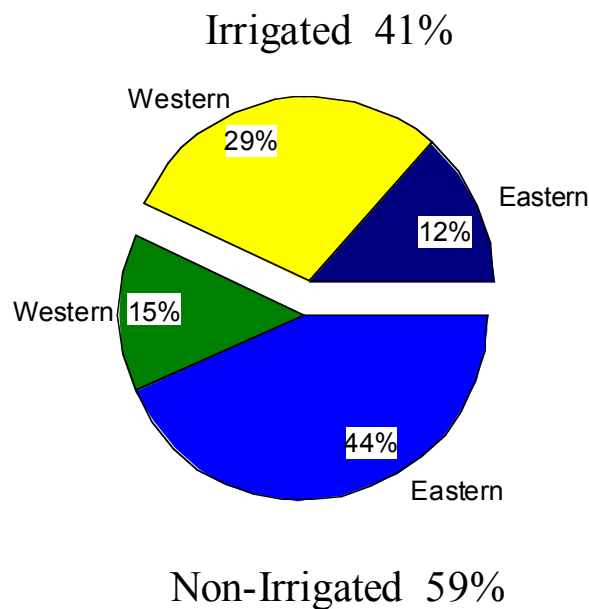
Source: USDA, ERS based on 1990 U.S. Geological Survey water use data.

Water Quality. Improved water management can also help minimize offsite water-quality impacts of irrigated production. Irrigated agriculture affects water quality in several ways, including higher chemical-use rates associated with irrigated crop production, increased field salinity and erosion due to applied water, accelerated pollutant transport with drainage flows, degradation due to increased deep percolation to saline formations, and greater instream pollutant concentrations due to reduced flows. Strategies to improve

the Nation's water quality must address the effect of irrigation on surface- and ground-water bodies (National Research Council, 1996).

Farm Returns. Finally, improvements in IWM can help maintain the long-term viability of the irrigated agricultural sector. Irrigated cropland is important to the U.S. farm economy, accounting for about 41 percent of total crop sales with just 15 percent of the Nation's harvested cropland in 1992 (see Figure 6; USDC, 1994). Water savings at the farm level can help offset the effect of rising water costs and restricted water supplies on producer income. Improved water management may also reduce expenditures for energy, chemicals, and labor inputs, while enhancing revenues through higher crop yields and improved crop quality.

Figure 6. Distribution of 1992 Crop Sales in U.S. by Irrigation Status and Region (Western Region - the seventeen contiguous western states)

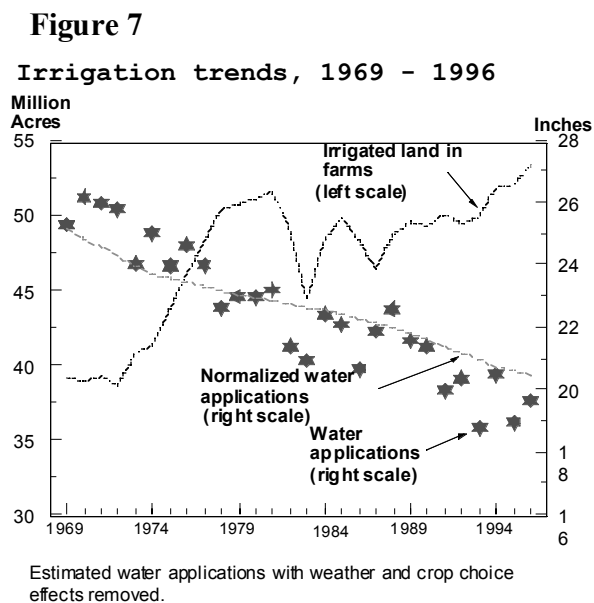


Source: USDA, ERS based on 1992 Census of Agriculture data.

Irrigation Water Application Rates and Irrigated Land in Farms

Since 1969, the national average irrigation water application rate has declined by about 6 inches, or 25 percent, which is enough to offset the increase irrigated acreage and maintain total water applied near the level of 25 years earlier (see Figure 7). Reductions in application rates have been widespread, with the greatest declines in the Northern Plains and Mountain regions.

Of the 6-inch decline in applied water, 2 to 3 inches are attributable to shifting shares of irrigated crop production between States and between crops within States. Recent growth in irrigated area has come in cooler northern States or humid eastern States with lower water application requirements. The remaining 3 to 4 inches of decline in application rates represent efficiency gains from changes in irrigation technologies and water management practices.



Source: USDA, ERS.

Use of Improved Irrigation Technology and Management

Producers may reduce water use per acre by applying less than full crop-consumptive requirements (deficit irrigation), shifting to alternative crops or varieties of the same crop

that use less water, or adopting more efficient irrigation technologies. In some cases, producers may convert from irrigated to dryland farming or retire land from production. Many irrigators have responded to water scarcity through the use of improved irrigation technologies--often in combination with other water-conserving strategies--and irrigators will likely look to technology as a means of conserving water in the future.

Various management practices and irrigation technologies are available to enhance efficiency of applied water in irrigated agriculture (see section, "Irrigation Water-Use Efficiency"). Irrigation improvements often involve upgrades in physical application systems, with improved field application efficiencies and higher yield potentials (see Table 1). Improved water management practices may also be required to achieve maximum potentials of the physical system. In some cases, the effectiveness of improved irrigation practices may be enhanced when implemented in combination with other farming practices such as conservation tillage and nutrient management.

Table 1 -- Changes in irrigation system acreage, 1979-94

System	1979	1994	Change 1979-94
	<i>Million acres</i>		<i>Percent</i>
All systems	50.1	46.4	-7
Gravity-flow systems	31.2	25.1	-20
Sprinkler systems	18.4	21.5	17
Center pivot	8.6	14.8	72
Mechanical move	5.1	3.7	-27
Hand move	3.7	1.9	-48
Solid set and permanent	1.0	1.0	2
Low-flow irrigation (drip/trickle)	.3	1.8	445
Subirrigation	.2	.4	49

Source: USDA, ERS, based on USDC, 1982 and 1996.

Efforts to increase irrigation efficiency can directly affect crop consumptive use in two ways. The greater uniformity of applied water associated with many improved technologies may result in higher crop yields, with resulting increases in consumptive water requirements. That is, the water "saved" through improved efficiency is used to augment crop yield on the same field. This may reduce the amount of water that is available to downstream users that have depended on the return flow to surface streams or ground water for their water rights. Some of the "saved" water through improved efficiency may be available for other uses--subject to conveyance and legal restrictions. The same water cannot be allocated more than once.

While opportunities exist to further increase onfarm water-use efficiency in irrigated agriculture, the quantity of "new" water through reduced irrigation losses will depend on various factors. The effectiveness of onfarm improvements augmenting water flows for instream and onfarm uses may be limited by increased consumptive water use from expanded onfarm production, reduced irrigation return flows to recharge ground water and surface-water systems, and limits on efficiency gains due to widespread irrigation improvements already in place. In addition, the availability and use of conserved water offsite depend on the physical storage and delivery system, the structure of water rights, and the availability of water to satisfy all claims. Where "saved" flows are available as increased non-reserved flows, and junior water-right holders receive only partial entitlements, water conserved upstream may be claimed by downstream irrigation interests. Unintended environmental impacts that can accompany improved efficiencies--such as reductions in downstream wetland habitat, groundwater recharge, and stream return-flow--may be of concern in some areas.

Other Practices Affecting Irrigation

Other practices--while not water-management practices *per se*--can be important components of an irrigated farming system. Such practices, in combination with improved irrigation systems, may enhance returns to irrigated production while reducing offsite environmental impacts.

For example, irrigation affects the optimal timing and application rate of chemical applications for nutrient and pest management. Fertilizer use is typically greater for high-yielding irrigated production. Weed and pest conditions may also increase under irrigated field conditions, necessitating increased use of pesticides, herbicides, and fungicides. Careful nutrient and pest management increases the effectiveness of water and applied chemicals, while reducing offsite impacts.

Factors Affecting Technology Adoption

The choice of irrigation technology is highly site-specific, reflecting locational, technical, and market factors. Field characteristics--such as field size and shape, field gradient, and soil type--are perhaps the most important physical considerations in selecting an irrigation system. Other important factors include technology cost (useful life, financing options); water supply characteristics (cost, quality, reliability, flow rate); crop characteristics (spacing, height); climate (precipitation, temperature, wind velocity);

market factors (crop prices; energy cost, labor supply); producer characteristics (farming traditions; management expertise, risk aversion, tenant/owner status, commitment to farming); and regulatory provisions (groundwater pumping restrictions, drainage discharge limits, water transfer provisions). In many cases, current technology choice is limited by fixed investments in existing systems at the site.

The 1994 Farm and Ranch Irrigation Survey (FRIS) reports that 38 percent of farms made system improvements from 1990 to 1994, while no improvements were reported on 56 percent of farms. Those farms reporting improvements tended to be larger, accounting for 58 percent of the irrigated acres. FRIS collected information on several key factors affecting technology adoption--including capital requirements, technology information, water-pricing policy, and water-supply considerations.

Capital requirements

Improvements in irrigation systems are often highly capital intensive. FRIS reports that investment in onfarm irrigation equipment, facilities, and land improvements totaled \$800 million in 1994, or nearly \$10,000 per farm reporting expenditures (USDC, 1996).

Capital expenditures included \$573 million for irrigation equipment and machinery, \$92 million for construction and deepening of wells, \$82 million for permanent storage and distribution systems, and \$51 million for land clearing and leveling. Replacement of existing systems accounted for the largest share of irrigation capital expenditures (64 percent), followed by irrigation expansion (19 percent) and conservation improvements (17 percent).

Water supply

The off-farm water storage and delivery system may limit improvements in irrigation management at the farm-level. High onfarm water-use efficiency depends on adequate and timely supplies of water. This requires a flexible surface-water system with sufficient off-farm storage and conveyance capacity, and effective control facilities and operating policies. Many older conveyance systems cannot be adapted to delivering water on demand without capital improvements. Limited off-farm water storage may further restrict water deliveries. Coordination is needed between the off-farm conveyance system and onfarm irrigation system to ensure compatible design and water-scheduling procedures.

Uncertainty of water supplies is an additional limiting factor. Surface-water supplies for junior water-right holders often vary significantly with water storage conditions and other factors. Producers may apply excessive water during peak-flow periods to buffer the effects of potential late-season shortages. Variable water supplies may also restrict investment in more efficient structural system improvements, while favoring the use of portable systems and development of supplemental groundwater supplies. Risk of loss of future water rights further limits incentives to invest in water-conserving technologies.

Irrigation Water-Use Efficiency

Water-use efficiency measures are commonly used to characterize the water-conserving potential of irrigation systems. Alternative efficiency measures reflect various stages of water use and levels of spatial aggregation. **Irrigation efficiency**, broadly defined at the field level, is the ratio of the average depth of irrigation water beneficially used (consumptive use plus leaching requirement) to the average depth applied, expressed as a percentage. **Application efficiency** is the ratio of the average depth of irrigation water stored in the root zone for crop consumptive use to the average depth applied, expressed as a percentage. Crop-water consumption includes stored water used by the plant for transpiration and tissue building, plus incidental evaporation from plant and field surfaces. Leaching requirement, which accounts for the major difference between irrigation efficiency and application efficiency, is the quantity of water required to flush soil salts below the plant root zone. Field-level losses include surface runoff at the end of the field, deep percolation below the crop-root zone (not used for leaching), and excess evaporation from soil and water surfaces. **Conveyance efficiency** is the ratio of total water delivered to the total water diverted or pumped into an open channel or pipeline, expressed as a percentage. Conveyance efficiency may be computed at the farm, project, or basin level. Conveyance losses include evaporation, ditch seepage, operational spills, and water lost to noncrop vegetative consumption. **Project efficiency** is calculated based on onfarm irrigation efficiency and both on- and off-farm conveyance efficiency, and is adjusted for drainage reuse within the service area. Project efficiency may not consider all runoff and deep percolation as loss since some of the water may be available for reuse within the project.

Summary

The subject of water use efficiency is quite complex and often misunderstood both within and outside the scientific communities. The information presented herein has identified the major factors contributing to improvements in WUE in both the U. S. irrigated and non-irrigated agriculture sectors. WUE in the U.S. has increased dramatically during the

last half of the Twentieth Century. This rate of increase is expected to continue as new technologies, especially in the area of biotechnology, are developed and implemented and factors affecting adoption of existing technologies are overcome.

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The primary resource for the information herein is the report Agricultural Resources and Environmental Indicators (AREI), 1996-97, Agricultural Handbook Number 712, Economic Research Service, United States Department of Agriculture. Specific chapters of the AREI used (in part) include 2.1 Water Use and Pricing, 3.1 Nutrients, 3.2 Pesticides, 4.2 Crop Residue Management, 4.6 Irrigation Water Management, and 5.1 Agricultural Technology Development. The AREI is available on the World Wide Web at <http://www.econ.ag.gov/epubs/pdf/ah712/index.htm>.

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